EPJ manuscript No.
(will be inserted by the editor)

Multiplicities and particle production at LEP*

Edward K. G. Sarkisyan[1,2]

[1] EP Division, CERN, CH-1211 Geneva 23, Switzerland
[2] Department of Physics and Astronomy, The University of Manchester, Manchester, M13 9PL, UK

Received: date / Revised version: date

Abstract. Recent results on hadron multiplicities in heavy and light quark fragmentation above the Z^0 peak (OPAL), and multiplicity distribution analysis (L3) and inclusive f_1 production (DELPHI) in hadronic Z^0 decays are presented.

PACS. 12.38.Qk – 13.66.Bc

1 Hadron multiplicities in heavy and light quark fragmentation

OPAL presents the recent measurements of charged hadron multiplicities in heavy and light quark initiated events from the full statistics collected at LEP1.5 and LEP2 [1]. The study of the quark content in multiparticle production provides one of the basic tests of QCD. The results from LEP are of a special interest since they cover a wide centre-of-mass energy region and can be directly compared with QCD which is mostly predictable at asymptotic energies [2].

In [1], OPAL performs a study of the fragmentation of heavy b-quark and light quarks (l = u, d, s). The measurements of the difference in charge particle multiplicities, $\delta_{\rm bl} = \langle n_{\rm b\bar{b}} \rangle - \langle n_{\rm l\bar{l}} \rangle$, for $\rm b\bar{b}$ and $\rm l\bar{l}$ events in $\rm e^+e^-$ annihilation at the centre-of-mass energies above the Z^0 peak are carried out. The findings are compared to the theoretical predictions of QCD [3,4,5] and to a more phenomenological (the so-called naïve) model [6] (for a review see [2]). The QCD calculations predict energy independent behaviour of the multiplicity difference $\delta_{\rm bl}$, while in the naïve model one expects the decrease with increasing energy. The latter is connected with the assumption that the hadron multiplicity accompanying the heavy hadrons in $\rm b\bar{b}$ events is the same as the multiplicity in $\rm l\bar{l}$ events at the energy left to the system once the heavy quarks have fragmented. The lower energy measurements could not discriminate between the two approaches, see Fig. 1.

The difference between the heavy and light mean quark-pair multiplicities obtained by OPAL in the energy range up to 206 GeV is shown in Fig. 1 along with all previously published results and compared to the QCD predictions. OPAL obtains the luminosity weighted up to 195 GeV $\delta_{\rm bl}$ average value $\delta_{\rm bl} = 3.44 \pm 0.40(\rm stat) \pm 0.89(\rm syst)$ GeV [1]. This result, which differs numerically (due to some differences in the data processing procedure) from that from DELPHI, $\delta_{\rm bl} = 4.26 \pm 0.51(\rm stat) \pm 0.46(\rm syst)$ [7], leads to the conclusion on the energy independence of $\delta_{\rm bl}$. This finding favours the QCD prediction while it is inconsistent with the flavour independent naïve model what now is confirmed by LEP with high accuracy.

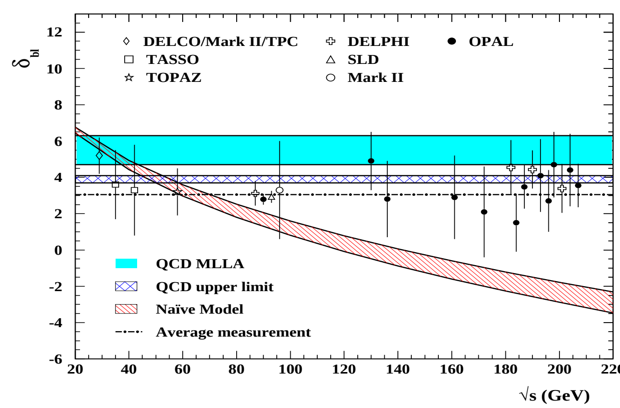

Fig. 1. The difference in the mean charged multiplicities, $\delta_{\rm bl}$, between heavy and light quark pairs as a function of centre-of-mass energy. The dashed-dotted line is the combined result from all measurements. The following predictions are shown: the MLLA prediction [3] (does not include higher-order corrections), the QCD upper limits as in [4], and the naive model calculations [6]. See [1] for more details.

2 H_q-moment analysis of the multiplicity distribution in hadronic Z decays

L3 reports on the charged-particle multiplicity study in terms of H_q moments [8]. The H_q moments [9] are con-

* Talk given at the International Europhysics Conference on High Energy Physics, EPS-HEP2003, 17-23 July 2003, Aachen, Germany.

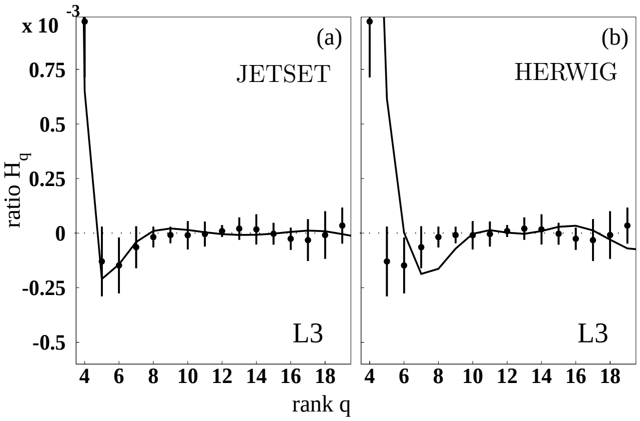

Fig. 2. The H_q moments of the charged-particle multiplicity distributions of L3 compared to the predictions of (a) Jetset and (b) Herwig Monte Carlo models, as reported in [8].

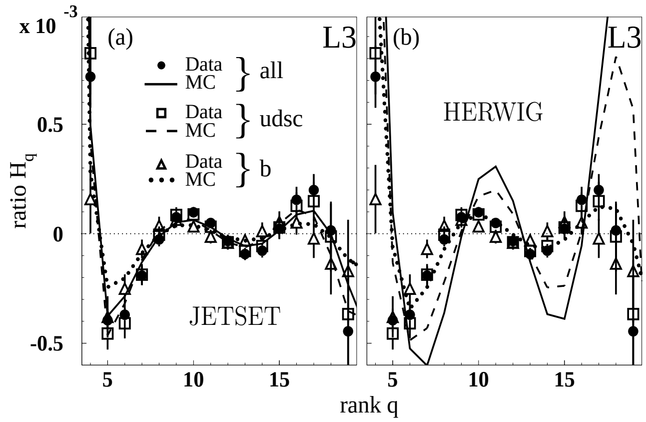

Fig. 3. The H_q moments of the *truncated* charged-particle multiplicity spectra for all, udsc-, and b-quark events of L3 data compared to the predictions of (a) Jetset and (b) Herwig Monte Carlo models, as reported in [8].

structed as a ratio of cumulants to factorial moments and look to be more convenient to be studied since they do not increase so rapidly with rank q as the cumulants or factorial moments do [10]. Meanwhile, the H_qs exhibit all the qualitative features of the cumulants, particularly their property to extract genuine q-particle correlations. For a review see [11].

The moments H_q appear as the solution of the QCD equations for the generating function. Their q-dependence is quite sensitive to the approximation used: $H_q = 1/q^2$ in the double-log approximation (DLA), they have a minimum at $q_{\min} \approx 5$ in the modified leading-log approximation (MLLA or next-to-leading order NLO), and oscillate around zero for higher NLO terms, e.g. NNLO. The minimum and the oscillations are observed experimentally in different type of collisions, while there is still no clear understanding of the physical origin of the oscillations. Those could appear e.g. due to energy-momentum conservation (which is incorporated in Monte Carlo models and in NNLO), the flavour content, the restrictions of finite energy (maximum multiplicity cutoff) etc.

To note is that local parton-hadron duality hypothesis (LPHD) [12] assumes that hadronic spectra are proportional to the partonic ones the theory (OCD) deals with (for a review see [2]). If this is valid, the same behaviour may be expected for the experimentally observed multiplicity distributions as for the parton one.

Fig. 2 shows the H_q moments measured by L3 from the 1.5M Z decays sample compared to the expectation of the Monte Carlo models, Jetset with string fragmentation and Herwig of cluster fragmentation. The moments have a minimum at $q = 5$, while the oscillations seem to be statistically insignificant. This agrees qualitatively with MLLA and NNLO but does not confirm the oscillations predicted. Jetset agrees well with data and shows the same $q_{\min}$, while the minimum is shifted to higher q values in Herwig.

The absence of the oscillations disagrees with earlier results from different reactions [13] and in particular with those from e^+e^- collisions at the same energy (SLD [14]) (see also [11]). Since it has been suggested [15] that the oscillatory behaviour of the H_q could be affected by the multiplicity distribution truncation[1] (SLD), the multiplicities with relative error greater than 50% in the multiplicity distribution were rejected ($\sim$0.005% of events).

The H_q ratios for the truncated multiplicity are measured for all, udcs-, and b-quarks as shown in Fig. 3. Despite the moments have a first minimum at $q = 5$, they *do* exhibit quasi-oscillatory behaviour for higher ranks. No sensitive differences are visible among all three samples. The oscillations are well reproduced by Jetset, while the minima are shifted to higher qs and are larger in Herwig.

L3 concludes that the measurements qualitatively agree with MLLA and NNLO, i.e. show a negative minimum at $q = 5$, but do not confirm the oscillatory behaviour predicted by high-order NLO. The measurements are well described by Jetset.

Recently, in [16] it has been shown that from theoretical point of view the *un*truncated moments have to be a subject under investigation and not the truncated ones. The very small values of the oscillation amplitudes of untruncated H_qs are shown to follow well the MLLA predictions.

3 Inclusive $f_1(1285)$ and $f_1(1420)$ production

DELPHI reports on the hadron spectroscopy measurement of the inclusive production of two $(K\overline{K}\pi)^0$ states in the mass range 1.2–1.6 GeV/c^2 in hadronic Z^0 decays. The measurements are based on the neutral $K\overline{K}\pi$ channel in the reaction $Z^0 \to K_S K^\pm \pi^\mp + X^0$, where the two 3-body states in the channel are ascribed to $f_1(1285)$ and $f_1(1420)$ mesons.

The $f_1(1285)$ and $f_1(1420)$ are the mesons belonging to the P-wave hadron multiplets $^3P_1$ which (along with the $^1P_1$) are very little studied in contrast to the well established S-wave (π, ρ) and other P-wave, $^3P_2$ and $^3P_0$ (e.g.

[1] This already occurs naturally as a consequence of the limited size of the number of events and the multiplicity per event.

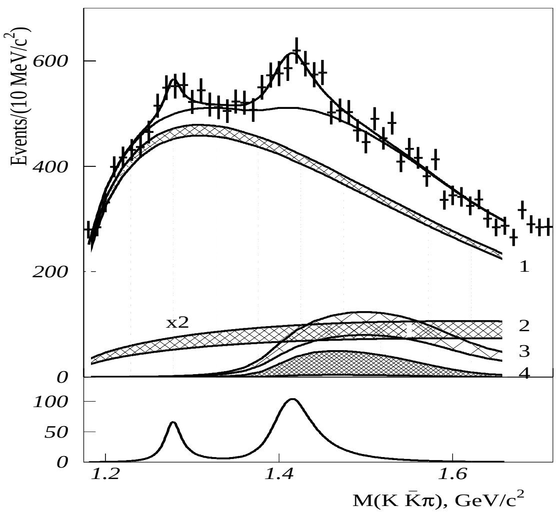

Fig. 4. $K_S K^{\pm}\pi^{\mp}$ invariant mass distribution measured by DELPHI [17] with a breakdown into the partial waves for the signals (lower histogram) and the background (one error band). The signals consist of $J^{PC} = 1^{++}a_0(980)\pi$ (first peak) and $1^{++}K^*(892)\overline{K}$ (second peak). The background includes: (1) isotropic phase space distribution, and (shown magnified by a factor of two) the partial waves of (2) $0^{-+}a_0(980)\pi$, (3) $1^{++}K^*(892)\overline{K}$, and (4) $1^{+-}K^*(892)\overline{K}$.

$f_2(1270)$, $f_0(980)$), mesons [18]. Given the complexity of quark content and possible states to exist in the $(K\overline{K}\pi)^0$ systems, the study requires high accuracy in the selection and analysis procedures available at LEP. To note is that this is the first study of the inclusive production of two $J^{PC} = 1^{++}$ mesons.

A data sample of 3.4M events was processed. After the hadronic event selection, specific requirements on the tracks were imposed to extract the resonances for the $K_S K^{\pm}\pi^{\mp}$ system. The only events containing at least one $K_S K^+\pi^-$ or $K_S K^-\pi^+$ combination are used in the analysis, corresponding to a sample of about half a million events. In the study the two methods, $K_S K^{\pm}\pi^{\mp}$ mass spectra and the partial wave analysis (PWA), are applied. To maximize both f_1 mesons signals over background, the data were estimated using Monte Carlo events with a mass cut $M(K_S K^{\pm}) \leq 1.4$ GeV/c^2.

The $(K\overline{K}\pi)^0$ mass spectra are fitted in the region 1.19 to 1.7 GeV/c^2 with a two S-wave Breit-Wigner forms and a specific background function. From the fits the masses and widths for the two f_1 mesons are estimated to be, respectively, 1274 ± 6 and 29 ± 12 MeV/c^2 for $f_1(1285)$ and 1426 ± 6 and 51 ± 14 MeV/c^2 for $f_1(1420)$, where the errors are the total, statistical and systematic, ones. The corresponding efficiencies for the two f_1s are (in %): $(63\pm3)\times10^{-3}$ and $(45\pm2)\times10^{-2}$ (Monte Carlo estimate).

To get more information on the spin content of the two signals a mass-dependent 3-body PWA [18] is applied to the $K_S K^{\pm}\pi^{\mp}$ system. The Dalitz plots with integrating over three Euler angles are fitted providing the contribution of the various J^{PC} waves as a function of $M(K_S K^{\pm})$. The comparison between fits uses their maximum likelihood values and their description of the $(K\overline{K}\pi)$, $(K\pi)$ and $(K\overline{K})$ mass distributions. The best fit with the estimated possible background contributions are shown in Fig. 4 and the values obtained are consistent with the values obtained from the mass spectra study. The (major) systematic uncertainties come from the background description and the PWA fit conditions. To estimate them, different fits have been carried out. A PWA of the $(K\overline{K}\pi)^0$ system shows that the first peak is consistent with the $I^G(J^{PC}) = 0^+(1^{++})a_0(980)\pi$ or $0^+(0^{-+})a_0(980)\pi$ waves and the second with the $I^G(J^{PC}) = 0^+(1^{++})K^*(892)\overline{K} + \text{c.c.}$

The analysis of the measured hadronic production rates per hadronic Z decay, 0.165 ± 0.051 and 0.056 ± 0.012, respectively, for the lower and for the higher mass signals obtained, suggests that their quantum numbers are very probably $I^G(J^{PC}) = 0^+(1^{++})$. The comparison of the present measurements to the LEP averaged total production rates per spin state and isospin for scalar, vector and tensor mesons as a function of mass suggests, in its turn, the two mesons quark constituents to be mainly $u\overline{u}$ and $d\overline{d}$. All this confirms that the measured states are very likely $f_1(1285)$ and $f_1(1420)$ mesons.

I am thankful to the EPS-HEP2003 Organising Committee, to convenors of the Hadronic Physics Session, and to my colleagues at CERN and particularly in OPAL for giving me the opportunity to give this talk and for their kind assistance and support.

References

1. OPAL Collab., G. Abbiendi, et al., Phys. Lett. B **550**, 33 (2002), EPS-HEP2003 abs. 763.
2. V.A. Khoze, W. Ochs, Int. J. Mod. Phys. A **12**, 2949 (1997).
3. B.A. Schumm, et al., Phys. Rev. Lett. **69**, 3025 (1992).
4. V.A. Petrov, A.V. Kisselev, Z. Phys. C **66**, 453 (1995); Nucl. Phys. B (Proc. Suppl.) **39B**, 364 (1995).
5. J. Dias de Deus, Phys. Lett. B **355**, 539 (1995).
6. Mark II Collab., P.C. Rowson, et al., Phys. Rev. Lett. **54**, 2580 (1985); A.V. Kisselev, V.A. Petrov, O.P. Yushchenko, Z. Phys. C **41**, 521 (1988).
7. DELPHI Collab., P. Abreu, et al., Phys. Lett. B **479**, 118 (2000), **492**, 398(E) (2000); DELPHI 2002-052 CONF 586.
8. L3 Collab., L3 Note 2808, 2003, Phys. Lett. B (to appear), EPS-HEP2003 abs. 190.
9. I.M. Dremin, Phys. Lett. B **313**, 209 (1993).
10. E.A. De Wolf, W. Kittel, I.M. Dremin, Phys. Rep. **270**, 1 (1996).
11. I.M. Dremin, J.W. Gary, Phys. Rep. **349**, 301 (2000).
12. Ya.I. Azimov et al., Z. Phys. C **27**, 65 (1985), **31**, 213 (1986).
13. I.M. Dremin, et al., Phys. Lett. B **336**, 119 (1994).
14. SLD Collab., K. Abe, et al., Phys.Lett. B **371**, 149 (1996).
15. A. Giovannini, S. Lupia, R. Ugoccioni, Phys. Lett. B **342**, 387 (1995).
16. M.A. Buican, C. Förster, W. Ochs, Eur. Phys. J. C **31**, 57 (2003), hep-ph/0307234.
17. DELPHI Collab., J. Abdallah, et al., Phys. Lett. B **569**, 129 (2003), EPS-HEP2003 abs. 323.
18. Particle Data Group, K. Hagiwara, et al., Phys. Rev. D **66**, 010001 (2002).